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High-Rate Mechanical Response of Next-Generation Gun Propellants

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Abstract

The material test systems (MTS) servohydraulic tester (SHT) high-rate mechanical response of three lots of next-generation high-energy gun propellants was tested. The U.S. Army Armament Research, Development, and Engineering Center (ARDEC) materials were designated by lot numbers 8177 thermoplastic elastomer (TPE)-based sheet material, 8183 TPE-based sheet material, and 8188 nitrocellulose (NC)-based sheet material. The lots are candidate propellants for the M829E3 120-mm tank gun round (Test Sets 12–20/FY00).

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1. Background

The U.S. Army Research Laboratory (ARL) received three lots of next-generation high-energy 120-mm gun (Figure 1) propellants from Thelma Manning of the U.S. Army Armament Research, Development, and Engineering Center (ARDEC). Lots 8177 and 8188 were manufactured as single-perforated granular propellants with diameters of ~6.40 mm, and lot 8183 was manufactured in a mixer and extruded thermally into sheet material. The sheet material had a thickness of ~2.80 mm. The sheet was cut into 25.40-mm × 25.40-mm squares, and several squares from the lot of the experimental gun propellant were shipped to Dr. Robert Lieb of ARL. Several lots of similar materials previously tested are included in the Appendix, and the mechanical properties may be used for comparative purposes as the test conditions were similar. The three lots of subject material were last tested for high-rate compressive mechanical response evaluation during February of 2000. Figure 2 is a photograph of the energetic material being loaded into the test apparatus.

2. Approach and Results

The propellant lot 8183 thermoplastic elastomer (TPE) based sheet material was received in solid sheet form without perforations. The lot was cut into samples and stacked, resulting in test specimens with an average length-to-diameter (L/D) ratio of 1.06. Sample preparation was accomplished using a 12.68-mm stainless steel hole punch. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis. The single perforated lots 8177 TPE-based sheet material and 8188 nitrocellulose (NC)-based sheet material were prepared into test specimens using an Isomet double-bladed diamond saw, and the sample ends were also machined flat. The prepared test specimens had an average L/D of 1.74.

Material Test Systems (MTS) servohydraulic tester (SHT) mechanical properties tests [1–7] were conducted on several specimens under each test condition. Average strain rates of 120.9 (1/s) were achieved. The specimens were taken to failure at ambient pressure to ~60% end

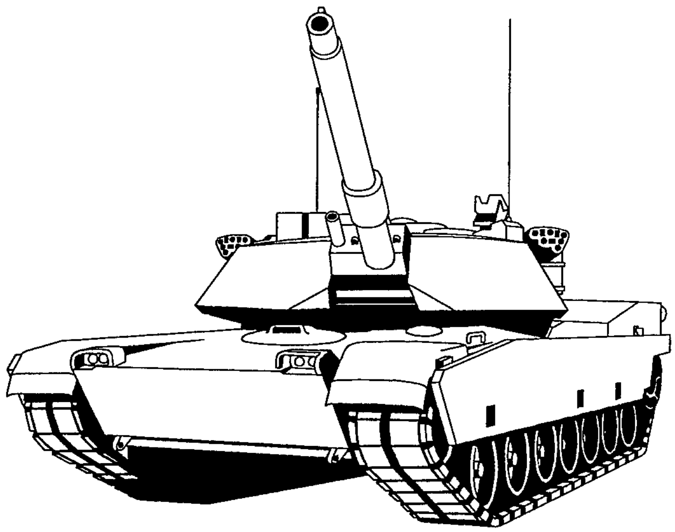

Figure 1. M1 Abrams With 120-mm Cannon.

Figure 2. Photograph of the Energetic Material Being Loaded Into Test Apparatus.

strain while conditioned at –21 °C, 50 °C, and –20 °C temperatures. The stress at failure, strain at failure, modulus, failure modulus, incremental energy density (IED), and fracture assessment value (FAV) were recorded for each test. The average values are listed in Table 1.

Table 1. Mechanical Properties of Lots 8177, 8183, and 8188 at 21 °C, 50 °C, and −20 °C

Lot No.	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure[a] Modulus (GPa)	IED[b] (MPa)	FAV[c]
21 °C						
Lot 8177 TPE-Based Single Perf.	57.04	4.80	1.780	−0.079	12.33	2AB
Lot 8183 TPE-Based Sheet Material	27.46	8.51	0.430	0.087	20.91	1B
Lot 8188 NC-Based Single Perf.	107.0	5.60	2.85	−0.010	24.59	3AB
50 °C						
Lot 8177 TPE-Based Single Perf.	21.11	4.22	1.01	−0.018	5.90	1B
Lot 8183 TPE-Based Sheet Material	15.78	7.77	0.280	0.069	14.53	1B
Lot 8188 NC-Based Single Perf.	72.45	4.50	2.24	−0.079	12.40	2AB
−20 °C						
Lot 8177 TPE-Based Single Perf.	94.09	2.32	6.09	−23.1	1.12	8AS
Lot 8183 TPE-Based Sheet Material	68.86	8.01	1.38	0.057	15.50	3AB
Lot 8188 NC-Based Single Perf.	139.17	5.20	3.53	−0.150	31.60	5AS

[a] The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (negative value indicates the material unable to sustain load). A positive value indicates a positive failure slope (material supports the load better).

[b] The IED value reported is the amount of energy absorbed at 25% strain; this includes a portion of the area located under the stress/strain curve.

[c] The tested specimens were assigned an FAV. The values range from 0 (no fractures) through 9 (severe fracturing). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, R = radial splitting (i.e., 8AS would indicate the tested specimens suffered severe axial and shear fracture).

3. Conclusions

Three lots of next-generation gun propellants were tested in uniaxial compression at an average 1.35-m/s deformation rate. The materials were taken to ~60% end strain while conditioned at 21 °C, 50 °C, and –20 °C (Figure 3). Several lots of similar materials tested using like conditions are included in the Appendix, and their values may be used for comparative purposes.

At 21 °C, lot 8183 showed impressive mechanical properties when compared with lots 8177 and 8188. The stress at failure, percent strain at yield, modulus, failure modulus, and energy density values were significantly better than either lot 8177, TPE-based single perf., or lot 8188, NC-based single perf. It should be noted, however, that the sheet configuration of lot 8183 was without perforations, which may account for the better mechanical response. The stress vs. strain (Figures 4–6) plot also confirms the better response by lot 8183. The tested specimens at 21 °C (Figure 3) showed permanent deformation/barreling of lot 8183 and permanent deformation/barreling and minimal axial fracture for lots 8177 and 8188.

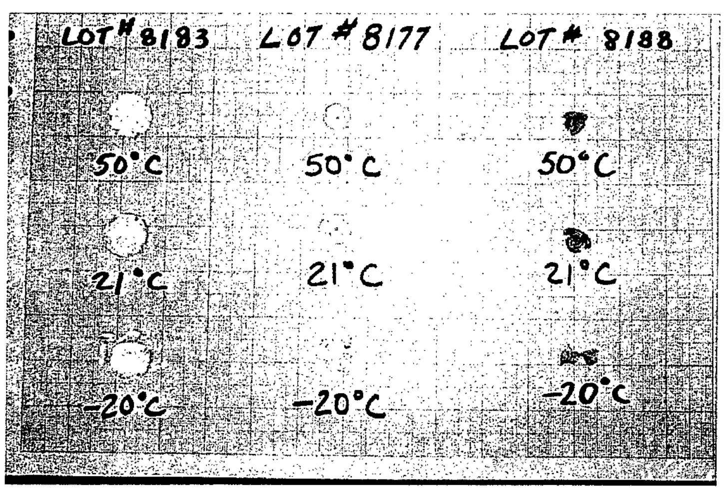

Figure 3. Lots 8183, 8177, and 8188 Tested at –20 °C, 21 °C, and 50 °C.

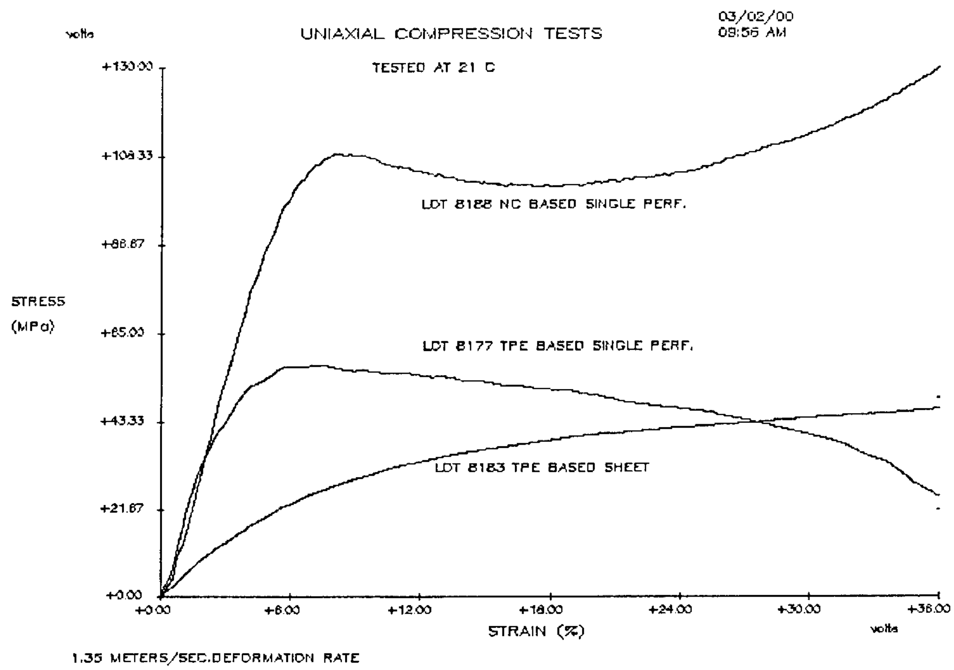

Figure 4. Stress vs. Strain Plot for Lots Tested at 21 °C.

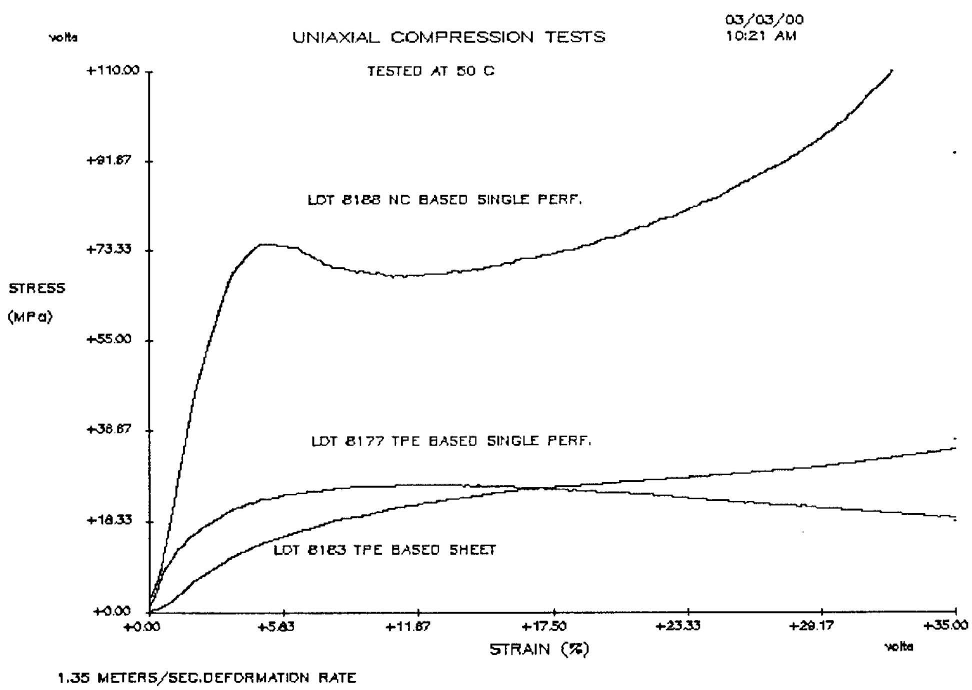

Figure 5. Stress vs. Strain Plot for Lots Tested at 50 °C.

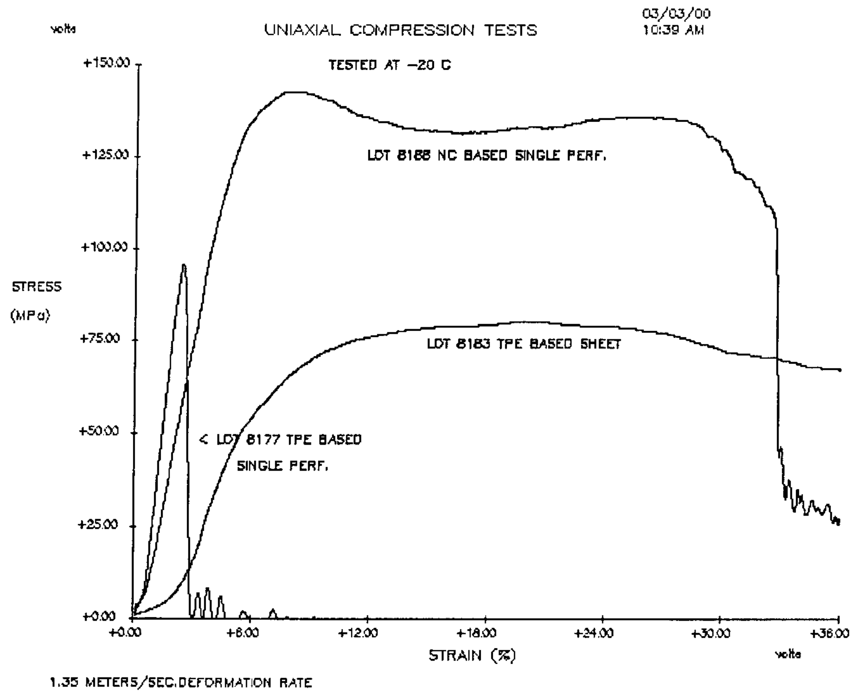

Figure 6. Stress vs. Strain Plot for Lots Tested at –20 °C.

At 50 °C, lot 8183 again showed the better mechanical properties when compared with lots 8177 and 8188. Note the positive failure modulus value achieved at 50 °C. This would indicate the material sustains the load better than lots 8177 and 8188, which both yielded negative failure modulus values. The tested specimens at 50 °C showed only permanent deformation and/or barreling for lots 8183 and 8177, both of which are TPE-based materials. Lot 8188, an NC-based material, showed minimal fracture damage as well as permanent deformation.

At –20 °C, lot 8183 once again showed an excellent mechanical response. The tested specimens showed only minimal fracture damage. The tested specimens from lots 8188 and 8177 suffered moderate to severe axial and shear fracture damage, respectively, likely causing significant increases in the surface area of these two lots. The stress/strain plots (Figure 6) for the materials also correlate with the physical damage observed. Note the sharp stress vs. strain pulse for lot 8177, which indicates the material had glass transitioned as a result of the –20 °C exposure. The negative failure modulus values achieved for lot 8188 and especially lot 8177

indicated both lots' inability to sustain load at –20 °C. Lot 8183, however, showed a positive failure modulus value, indicating that the material was better at sustaining load.

Overall, lot 8183 TPE-based sheet material showed superior mechanical properties when compared to the subject and appendix lots. The –20 °C values for lot 8177 are cause for concern, as the test results indicated the lot was sensitive to the colder testing temperature, becoming "brittle" at –20 °C and suffering prolific fracture.

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7. Lieb, R. J. Personal communication. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, February/March 2000.

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Appendix:

Mechanical Response of
Aerojet Lots 3663, 3736, and 3744

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Table A-1. Mechanical Properties of Lots 3663, 3736, and 3744 at 21 °C, 50 °C, and −20 °C

Lot No.	Stress at Failure (MPa)	Stress at Failure (%)	Modulus (GPa)	Failure Modulus (GPa)	IED (MPa)	FAV
21 °C						
AXF 3663 Lot 10TPG-41	37.30	6.30	0.855	−0.0426	7.02	1AB
AXF 3736 Lot 10TPG-40	58.01	5.75	1.27	−0.261	10.09	2AB
AXF 3744 Lot 10TPG-39	36.16	4.21	1.17	−0.471	2.02	2AB
50 °C						
AXF 3663 Lot 10TPG-41	21.10	6.00	0.485	−0.0260	4.34	1B
AXF 3736 Lot 10TPG-40	25.05	5.50	0.752	−0.0213	5.63	1B
AXF 3744 Lot 10TPG-39	26.66	5.61	0.982	−0.0488	5.24	1B
−20 °C						
AXF 3663 Lot 10TPG-41	89.56	6.02	3.73	−6.92	1.37	8AS
AXF 3736 Lot 10TPG-40	35.10	6.35	1.77	−1.45	0.990	9AS
AXF 3744 Lot 10TPG-39	13.50	4.27	1.75	0.934	0.911	9AS

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The material test systems (MTS) servohydraulic tester (SHT) high-rate mechanical response of three lots of next-generation high-energy gun propellants was tested. The U.S. Army Armament Research, Development, and Engineering Center (ARDEC) materials were designated by lot numbers 8177 thermoplastic elastomer (TPE)-based sheet material, 8183 TPE-based sheet material, and 8188 nitrocellulose (NC)-based sheet material. The lots are candidate propellants for the M829E3 120-mm tank gun round (Test Sets 12-20/FY00).

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